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“The Macroeconomic Effectiveness of Bank Bail-ins”*

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Abstract

We examine the macroeconomic implications of bailing-in banks’ creditors after a systemic financial crisis, whereby bank debt is partially written off. We do so within a RBC model that features an endogenous leverage constraint which limits the size of banks’ balance sheets by the amount of bank net worth. Our simulations show that an unanticipated bail-in effectively ameliorates macroeconomic conditions as more net worth relaxes leverage constraints, which allows an expansion of investment. In contrast, an anticipated bail-in will be priced in ex-ante by bank creditors, thereby transferring the bail-in gains from banks to creditors. Therefore the intervention has zero impact on the macroeconomy relative to the no bail-in case. The effectiveness of the bail-in policy can be restored by implementing a temporary tax on debt outflows once creditors start to anticipate a bail-in.

Keywords: Bail-In, Financial Frictions, Macrofinancial Fragility

JEL Classification: E32, E44, E50

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I. Introduction

In 2014 the European Union (EU) adopted the Bank Recovery and Resolution Directive (BRRD), in which a bail-in of bank creditors is the main tool to deal with failing banks. In that case, part of a bank's debt is written off, such that its creditors rather than taxpayers carry the burden from dealing with the bank failures. In this paper we investigate the macroeconomic effectiveness of such a bail-in through its impact on the credit transmission channel when the entire commercial banking system becomes undercapitalized in a financial crisis. We show that anticipation effects of a future (partial) debt write-off completely offset the positive effects from a bail-in on the banking sector's net worth. Therefore, the intervention has zero impact on the macroeconomy. The anticipation effects can be reduced by imposing a temporary tax on debt outflows once creditors start to expect a bail-in.

The most obvious example of a bail-in that deals with a systemic financial crisis is Cyprus in March 2013, after a haircut on Greek sovereign debt held by Cypriot banks initiated a financial crisis in its banking system. In addition, the adoption of the BRRD in 2014 made bank bail-ins the primary instrument to deal with failing banks in the EU. Therefore, future bail-ins are to be expected, including cases where they are used to deal with systemic banking crises. In such a scenario the results from our paper become relevant. One region where such a scenario could materialize is Southern-Europe. With more than 10% of total loans non-performing, the Southern-European banking system might still be undercapitalized, despite higher capital ratios. Hence future negative shocks can push these banking systems into a new financial crisis, in which a system-wide bank bail-in becomes a realistic scenario.

To investigate the macroeconomic effectiveness of bail-ins, we construct a closed economy real business cycle (RBC) model with financial frictions as in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). In these models the size of banks' balance sheets is limited by an endogenous leverage constraint. Banks are financed through short-term debt and net worth.¹² An agency problem between creditors and banks constrains the latter's ability to raise short-term debt, which is the only asset through which households can save. Bail-ins are modeled as an exogenously imposed reduction of both principal and interest rate payments on short-term bank debt. A partial write-off of short-term debt liabilities effectively raises banks' net worth compared with the case where no bail-in is applied, everything else equal. The government has the possibility to impose a tax on

¹ Throughout the paper we will interchangeably use the terms 'banks' and '(financial) intermediaries'.

² Throughout the paper we will interchangeably use the terms 'short-term debt' and 'deposits' to denote every possible type of debt-financing through which banks fund themselves in reality. In the same vein, we will interchangeably use the terms 'creditors' and 'depositors'.

debt-funding that is not rolled over. We do not distinguish between insured deposits and other types of uninsured debt-financing, and assume that all debt holdings are subject to a bail-in.³

To the best of our knowledge, we are the first to assess the macroeconomic impact of a financial-sector-wide bail-in through a partial write-off of bank debt. An important contribution is to show that anticipated bail-ins can only be effective in raising investment and output when they are accompanied by an (unexpected) introduction of a tax on debt-funding that is not rolled over. In an international environment that would amount to the introduction of capital controls, such as happened in Cyprus at the moment a banking-sector-wide bail-in was agreed to recapitalize the Cypriot banking sector.

Our main findings are as follows. First, we show that an unanticipated bail-in of bank creditors, implemented the moment a systemic financial crisis hits, has a positive effect on the macroeconomy. As bank debt is partially written off, banks' net worth increases with respect to the case where no bail-in is implemented. Since banks are undercapitalized in a financial crisis, higher net worth relaxes their leverage constraints. As such, credit provision falls by less, moderating the fall in investment and output.

Second, an unanticipated bail-in is unlikely to occur in practice: usually investors and financial markets learn about financial troubles in the banking system (and hence the possibility of a bail-in) before these problems are officially acknowledged by regulators. Even if they do not, there might be legal and political constraints preventing regulators from immediately imposing a bail-in. Therefore, investors often anticipate the possibility of a future bail-in. We therefore investigate an anticipated bail-in which depositors start to expect as a financial crisis hits, but which is implemented one quarter later. From this experiment, we establish our second and main result: the macroeconomic effect of an anticipated bail-in is zero. The intuition behind this stark and seemingly counter intuitive result is the following: households start withdrawing their short-term deposits from the bank in the period before they (correctly) expect the bail-in to be implemented. With perfect competition in the deposit market, and prices and interest rates perfectly flexible, banks are forced to raise the interest rate on deposits to such an extent that the higher interest rate exactly compensates for the losses incurred from the partial write-off of deposit liabilities. In equilibrium, no deposits are withdrawn with respect to the case where no bail-in is implemented, and no gain in net worth is realized. Therefore, the intervention has zero impact on the real economy.

Our third result is that the effectiveness of an anticipated bank bail-in can be restored by imposing an (unexpected) temporary tax on the outflow of deposits at the moment households start

³ Even though in reality deposits up to €100,000 are protected by deposit insurance schemes (and would therefore not be subject to a bail-in), many bank deposits are not covered by such schemes, such as large cash holdings of corporations upwards of this amount. For example, the majority of the debt that was written off in the 2013 Cypriot bail-in consisted of deposits: €7.9 billion compared to a total of €9.4 billion (International Monetary Fund, 2014), indicating that a large share of deposits was not covered by any deposit insurance scheme. To further support our assumption of subjecting all debt-financing to a bail-in, we note that covered deposits make up a relatively small share of the balance sheet of financial institutions in the EU. For example, Schoenmaker and Gros (2014) estimate that this is approximately 18.5% of total EU bank liabilities. Given the relatively small share of debt-financing that is covered by deposit insurance, it is a reasonable approximation to assume that all debt is bailed-in.

to anticipate a bail-in. This raises the cost of withdrawing their deposits, which reduces the need for banks to raise interest rates to prevent deposit outflows, which would occur in the absence of such a tax. As such, the effect of the anticipated bail-in is offset within the household’s Euler equation, and thus an anticipated bail-in becomes qualitatively just as effective as an unanticipated bail-in in raising investment and output. This result rationalizes the decision by the Cypriot government to introduce capital controls (which can be thought of as a tax on capital outflows) after a bail-in of Cypriot banks’ creditors was agreed.

Literature review

This paper builds upon the literature that incorporates financial frictions in macroeconomic models, specifically Gertler and Karadi (2011), Gertler and Karadi (2013) and Gertler and Kiyotaki (2010). In these papers, an agency problem between depositors and bank managers forces banks to deleverage when a shock negatively affects their balance sheets, which reduces lending to the real economy. The innovation with respect to this literature is that we introduce the possibility of (partially) writing-off the value of deposit liabilities.

To the best of our knowledge, the only attempt at incorporating a ‘bail-in’ in a macroeconomic model is Breuss et al. (2015). They find that a bail-in is capable of mitigating the drop in output, as more bank capital allows an expansion of lending to the real economy. Their bail-in, however, is a one-off event that is unanticipated by depositors. We also find that an unanticipated bail-in has a positive effect on output, but in addition investigate the more realistic case where bail-ins are anticipated.

Our paper is also related to the newly developing literature that incorporates bank runs within DSGE models (Gertler and Kiyotaki (2015); Gertler et al. (2016); Gertler et al. (2017)), which is in these papers an equilibrium outcome, as negative shocks can push banks into insolvency. Even though depositors in our model start withdrawing their funds once they learn about the bail-in, banks do not become insolvent. Therefore, bank runs are not an equilibrium outcome, and depositors are in equilibrium always willing to provide funding as banks are forced to compensate for future bail-in losses through higher ex-ante interest rates.

Empirical evaluations of bail-ins are hard to come by, but Schäfer et al. (2016) provide an investigation into the market reactions of both credit default swap (CDS) spreads and stock prices of affected banks after a bail-in. They find that stock prices fell and banks’ CDS spreads increased after the Cypriot bail-in. Hüser et al. (2017) employ a multi-layered network model using European System of Central Banks (ESCB) proprietary data of the 26 largest euro area banking groups to assess the systemic implications of bail-ins.

The issue of bail-ins has also been examined in the corporate finance literature. Mendicino et al. (2017) investigate the optimal size and composition of banks’ total loss absorbing capacity (TLAC), for which bail-in debt can (partially) be used. Keister (2015) shows that a no bailout policy, which amounts to a bail-in policy, removes the distortion of ex-ante incentives that arises from the anticipation of a bailout, but may make the economy more susceptible to financial crisis. Taxing short-term liabilities offsets these negative effects on ex-ante incentives. Mitkov and Keister

(2017) study the interaction between a government’s bailout policy and the willingness of individual banks to impose bail-ins on their creditors. While these papers employ partial equilibrium models, and feature agency problems such as risk-shifting and private benefit taking, the crucial mechanism in our paper is driven by a general equilibrium effect, while we abstract from risk-shifting issues.

Our paper is also related to the literature that analyzes macro-prudential policy, and more specifically the literature in which (Pigouvian) taxes and/or subsidies are imposed to correct externalities (Gertler et al. (2012); Jeanne and Korinek (2010a); Jeanne and Korinek (2010b); Korinek (2011)). These externalities arise when individual market participants do not take the interaction between debt accumulation and asset prices into account that magnifies credit booms and busts. However, in our model such a tax is not imposed on bankers issuing more short-term debt, which would address this externality (see Gertler et al. (2012)), but rather on households to prevent them from taking out their deposit holdings.

This paper is structured as follows. Section II presents the model, and section III describes the calibration of the model. Section IV analyzes the effects of a bail-in after a financial crisis, while section V reflects and discusses our main findings and some of the underlying assumptions that drive them. Section VI concludes.

II. Model

We construct a closed economy RBC model with a banking sector à la Gertler and Karadi (2011). We extend their setup by including the possibility to bail-in bank creditors. Banks provide loans to final goods producers, who use these loans to purchase capital from capital goods producers. These banks are financed through net worth and short-term debt and are balance-sheet constrained due to an agency problem between banks and creditors (Gertler and Karadi, 2011).

Other agents considered in our model are households, non-financial firms, and a fiscal authority. Households consist of bankers who operate financial intermediaries, and workers who supply labor to final goods producers. At the end of the period, they pool resources to ensure perfect consumption insurance. Households can save, but only through short-term deposits that are potentially subject to a bail-in. In addition, the government has the possibility to impose a tax on deposit outflows from the banking system, which is then returned to households through a lump-sum transfer (Jeanne and Korinek (2010a); Jeanne and Korinek (2010b); Korinek (2011)). Final goods producers borrow from banks to purchase capital from capital goods producers and hire labor from households. Capital goods producers buy final goods and refurbish used capital, which they sell to final goods producers. The final good is consumed by households and sold to capital goods producers for investment purposes.

Our main innovation lies in the possibility to bail-in creditors, which is implemented through an exogenous reduction of deposit liabilities during or after a financial crisis: both the principal value and interest payments of bank debt are reduced. The introduction of this policy rule allows us to examine the anticipation effects of a bail-in in a relatively straightforward manner.

A. Households

Households are infinitely lived and have identical preferences. A fraction f of household members are workers and a fraction $1 - f$ bankers. Each household has perfect consumption insurance among its members. Households receive income from labor $W_t L_t$, gross interest payments (including repayment of principal) from deposits held at banks $(1 + r_{t-1}^d) D_{t-1}$, and profits from firms and banks owned Π_t . However, a fraction Ψ_t of gross interest payments will be written off and not repaid. If $\Psi_t = 0$, all deposit liabilities are honored by the bank, while $\Psi_t > 0$ denotes the bail-in case in which deposit liabilities are partially written-off. Therefore, post-bail-in gross deposits repayment equals $(1 + r_{t-1}^d) (1 - \Psi_t) D_{t-1}$. The functional form of Ψ_t is specified in section II.D. Income is spent on consumption C_t , savings in the form of bank debt D_t , lump-sum taxes T_t , and a tax τ_t on deposit outflows $D_{t-1} - D_t$ with respect to period $t - 1$. Hence households are taxed if they withdraw deposits from the bank, i.e $D_{t-1} > D_t$, while they are subsidized if they increase deposits ($D_{t-1} < D_t$). Within our model, this will be used as a temporary measure to induce households not to withdraw their deposits in times of financial crises. We assume utility is separable in consumption and labor, and assume habit formation in consumption to realistically capture consumption dynamics (Christiano et al., 2005). The household's optimization problem is to maximize expected discounted lifetime utility:

$$\max_{\{C_{t+s}, L_{t+s}, D_{t+s}\}_{s=0}^{\infty}} E_t \left\{ \sum_{s=0}^{\infty} \beta^s \left[\frac{1}{1-\sigma} (C_{t+s} - h C_{t+s-1})^{1-\sigma} - \frac{\chi}{1+\varphi} L_{t+s}^{1+\varphi} \right] \right\},$$

$$\beta \in (0, 1), h \in [0, 1), \varphi \geq 0,$$

where β is the household's discount factor, σ risk aversion, h habit persistence, χ the utility weight of labor, and φ the inverse Frisch elasticity of labor supply, while L_t denotes the number of hours worked. Households choose consumption, labor and savings subject to the following budget constraint:

$$C_t + D_t + T_t + \tau_t (D_{t-1} - D_t) = W_t L_t + (1 + r_{t-1}^d) (1 - \Psi_t) D_{t-1} + \Pi_t,$$

The standard first order conditions can be found in Appendix A.A. The only non-standard optimality condition is the household's Euler equation:

$$E_t \left[\beta \Lambda_{t,t+1} \left(\frac{(1 + r_t^d) (1 - \Psi_{t+1}) - \tau_{t+1}}{1 - \tau_t} \right) \right] = 1. \quad (1)$$

where $\beta \Lambda_{t,t+1} \equiv \beta \frac{\lambda_{t+1}}{\lambda_t}$ is the household's stochastic discount factor, and λ_t is the marginal utility of consumption. Unless otherwise specified, we set the tax on deposit outflows τ_t equal to zero, in which case the Euler equation collapses into:

$$E_t \left[\beta \Lambda_{t,t+1} (1 + r_t^d) (1 - \Psi_{t+1}) \right] = 1. \quad (2)$$

We see from (2) that households take the possibility into account that only a fraction $1 - \Psi_{t+1}$ of the promised gross interest payment will be honored when deciding how much to save. Therefore, expectations of a bail-in, captured by $\Psi_{t+1} > 0$, will affect the equilibrium interest rate on bank debt r_t^d : if Ψ_{t+1} increases, then r_t^d must increase to compensate for expected losses.

B. Non-financial firms

B.1. Final goods producers

A continuum of perfectly competitive final goods producers $i \in [0, 1]$ acquire loans from banks $S_{j,t-1}^k$ for a price Q_{t-1}^k to buy capital $K_{i,t-1}$ from capital goods producers. We assume that next period's profits can credibly be pledged to the bank (Gertler and Karadi, 2011). Using previous period's capital stock and labor, firms produce final goods using the following production technology:

$$Y_{i,t} = A_t \left(\xi_t^k K_{i,t-1} \right)^\alpha L_{i,t}^{1-\alpha},$$

where A_t and ξ_t^k are, respectively, technology and capital quality (Gertler and Karadi, 2011), both of which are driven by lognormal stochastic AR(1) processes. There is a perfectly competitive labor market in which workers are paid their marginal product. After production, the (depreciated) effective capital stock is sold to capital goods producers for a price Q_t^k . These revenues (net of wages) are used to repay the firm's loan, and thus determine the return on capital:

$$1 + r_t^k = \frac{\alpha \frac{Y_{i,t}}{K_{i,t-1}} + Q_t^k (1 - \delta) \xi_t^k}{Q_{t-1}^k}. \quad (3)$$

B.2. Capital goods producers

Capital goods producers buy the net effective capital stock $(1 - \delta) \xi_t^k K_{t-1}$ and I_t goods from final goods producers to combine used capital and final goods into new capital, which is sold to final goods producers for a price Q_t^k . We assume capital goods producers face convex adjustment costs. The law of motion for capital is then given by:

$$K_t = (1 - \delta) \xi_t^k K_{t-1} + \left[1 - \frac{\gamma}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t.$$

Profits for capital goods producers equal revenues from selling refurbished capital minus the costs of purchasing used capital and final goods. These are given by:

$$\Pi_t^k = Q_t^k K_t - Q_t^k (1 - \delta) \xi_t^k K_{t-1} - I_t.$$

The maximization problem is then to maximize the sum of current and expected discounted future profits by finding the optimal path for investment I_t . The solution to the problem is presented in Appendix A.B.2.

C. Banking sector

A continuum of banks $j \in [0, 1]$ act as intermediaries between savers and borrowers. Bank j extends loans to final goods producers $S_{j,t}^k$ for a price Q_t^k , which are funded by net worth $N_{j,t}$ and short-term debt $D_{j,t}$.⁴

$$Q_t^k S_{j,t}^k = N_{j,t} + D_{j,t}.$$

Loans pay a net return r_{t+1}^k in period $t + 1$. On the funding side, banks pay a net return on short-term debt r_t^d in period $t + 1$. However, they only pay a fraction $1 - \Psi_{t+1}$ of the promised gross interest payment $(1 + r_t^d) D_{j,t}$ (which includes repayment of the principal), where Ψ_{t+1} denotes the bail-in variable. Hence, in a bail-in ($\Psi_{t+1} > 0$), banks' net worth increases everything else equal because the gross interest payments on short-term debt $D_{j,t}$ are reduced by a fraction Ψ_{t+1} relative to the case with no bail-in. The law of motion for net worth of bank j is then given by:

$$\begin{aligned} N_{j,t+1} &= (1 + r_{t+1}^k) Q_t^k S_{j,t}^k - (1 + r_t^d) (1 - \Psi_{t+1}) D_{j,t} \\ &= (1 + r_{t+1}^k) Q_t^k S_{j,t}^k - (1 + r_t^d) D_{j,t} + \underbrace{\Psi_{t+1} (1 + r_t^d) D_{j,t}}_{\text{Bail-in gains}}, \end{aligned}$$

where we clearly see that the bail-in raises net worth of bank j by $\Psi_{t+1} (1 + r_t^d) D_{j,t}$ compared with the no bail-in case, everything else equal.

Bank j maximizes expected discounted future profits. Each period they face a constant probability of exit $1 - \vartheta$, in which case, the bank pays out its remaining net worth $N_{j,t+1}$ to the household. Banks continue operating with probability ϑ . Since banks are owned by households, expected future cash flows are discounted with the household's stochastic discount factor. The optimization problem is then characterized by the following recursively defined maximand:

$$V_{j,t} = \max_{\{S_{j,t}^k, D_{j,t}\}} E_t \{ \beta \Lambda_{t,t+1} [(1 - \vartheta) N_{j,t+1} + \vartheta V_{j,t+1}] \}.$$

Following Gertler and Karadi (2011), we assume that bankers have to possibility to divert assets during the transition to the next period. Creditors will then force the bank into bankruptcy, but can only recoup a fraction $1 - \lambda_k$ of assets, effectively leaving bankers with a share λ_k of assets. As creditors take the possibility of asset diversion into account, they are only willing to provide additional deposits as long as the continuation value of the intermediary exceeds the bank's gains from asset diversion, which gives rise to the following incentive compatibility constraint (ICC):

$$V_{j,t} \geq \lambda_k Q_t^k S_{j,t}^k.$$

⁴ We assume households bring their deposits to a bank other than the one they own to prevent self-financing, which would allow them to circumvent the incentive compatibility constraint to be introduced shortly.

We solve the bank's optimization problem in Appendix A.C.1, and find the following first order conditions for loans and net worth:

$$\nu_t^k = E_t \left\{ \Omega_{t,t+1} \left(1 + r_{t+1}^k - \left(1 + r_t^d \right) (1 - \Psi_{t+1}) \right) \right\}, \quad (4)$$

$$\eta_t = E_t \left\{ \Omega_{t,t+1} \left(1 + r_t^d \right) (1 - \Psi_{t+1}) \right\}, \quad (5)$$

where $\Omega_{t,t+1} \equiv \beta \Lambda_{t,t+1} \left[(1 - \vartheta) + \vartheta \left(\nu_{t+1}^k \phi_{t+1} + \eta_{t+1} \right) \right]$ is the bank's stochastic discount factor, which consists of the household's stochastic discount factor and a factor that captures financial frictions. The first order conditions introduce a new term compared to the literature, i.e. the bail-in term Ψ_{t+1} . In Appendix A.C.1 we show that we can write the ICC as:

$$\phi_t N_{j,t} \geq Q_t^k S_{j,t}^k, \quad \text{with} \quad \phi_t = \frac{\eta_t}{\lambda_k - \nu_t^k}, \quad (6)$$

where ϕ_t is the bank's endogenous leverage ratio. This condition shows that the size of the balance sheet is restricted by the amount of net worth of intermediary j .

C.1. Aggregation of financial variables

Integrating over all banks yields the following aggregate balance sheet of the banking sector:

$$Q_t^k S_t^k = N_t + D_t, \quad (7)$$

Since (6) does not depend on any individual bank characteristics, and assuming that the leverage constraint is always binding, the aggregate leverage constraint is given by:

$$\phi_t N_t = Q_t^k S_t^k. \quad (8)$$

Each period, a constant fraction $1 - \vartheta$ of bankers become workers, and bring their remaining net worth to the household, while ϑ bankers continue operating. Every period the number of new bankers that start operating a new bank equal the number of bankers that exited, such that the size of the banking sector is constant. Households provide new bankers with funds equal to a share of $\chi_F / (1 - \vartheta)$ of assets of bankers that exited. The aggregate law of motion for net worth is then given by the sum of net worth of old bankers and new bankers:

$$N_t = \vartheta \left[\left(1 + r_t^k \right) Q_{t-1}^k S_{t-1}^k - \left(1 + r_{t-1}^d \right) (1 - \Psi_t) D_{t-1} \right] + \chi_F Q_{t-1}^k S_{t-1}^k. \quad (9)$$

D. Government

D.1. Bail-in policy

A government regulator, e.g. the Single Resolution Board (SRB), can decide to implement a bail-in of creditors at all banks: in that case, a fraction $\Psi_t > 0$ of the gross interest payments on deposits

(including repayment of the principal) is written off, and does not need to be repaid by banks to creditors. The fraction of promised gross interest payment that is written off is given by an exogenous process which depends on the capital quality shock when $\varrho < 0$:

$$\Psi_t = \varrho \varepsilon_{\xi^k, t-l}. \quad (10)$$

The bail-in can be implemented immediately ($l = 0$) or with a lag ($l > 0$).

D.2. Fiscal authority

The fiscal authority levies lump sum taxes T_t on households and a tax τ_t on the change in households' short-term debt holdings D_t with respect to previous period's debt holdings D_{t-1} (Gertler et al., 2012; Jeanne and Korinek, 2010a,b; Korinek 2011). There are no government expenditures, as the government does not issue debt nor does it purchase any goods. Hence its budget constraint is given by:

$$T_t + \tau_t (D_{t-1} - D_t) = 0. \quad (11)$$

When $\tau_t = 0$, lump-sum taxes T_t are zero as well. However, when $\tau_t > 0$, and households withdraw deposits from the banking system ($D_{t-1} > D_t$), the revenues from the tax on deposit outflows are returned to households through a lump-sum transfer ($T_t < 0$). Vice versa, when households increase deposits with respect to the previous period ($D_{t-1} < D_t$), the government subsidy is paid by levying lump-sum taxes $T_t > 0$. The tax-rate on deposit outflows is given by:

$$\tau_t = \zeta \varepsilon_{\xi^k, t-z}. \quad (12)$$

When $\zeta < 0$, the tax on the change in households' short-term debt holdings increases if a negative shock to the quality of capital arrives. Like the bail-in policy, the tax can be implemented immediately ($z = 0$) or with a lag ($z > 0$). Unless otherwise specified, $\tau_t = 0$ in our simulations.

E. Market clearing

The goods market clears when output equals the sum of consumption and investment:

$$Y_t = C_t + I_t. \quad (13)$$

Loans to final goods producers must equal the total capital stock:

$$S_t^k = K_t. \quad (14)$$

III. Calibration

The model is calibrated on a quarterly frequency and largely follows Gertler and Karadi (2011) calibration for the United States. Table 1 presents an overview. We use the same parameter values for the share of capital in output α , the subjective discount factor β , investment adjustment costs γ , habit formation h , the inverse Frisch elasticity φ , and risk aversion σ . The disutility weight of labor χ is chosen to target a steady state labor supply of 1/3.

We also follow Gertler and Karadi (2011) for the calibration of the banking sector's parameters. As such, we set the aggregate leverage ratio to 4, and set the credit spread to 25 basis points per quarter in the steady state. The average survival time for bankers is set to 36 quarters, i.e. $\vartheta = 0.972$. The transfer to new bankers χ_F and the share of assets that bankers can divert λ_k are calibrated such that the previously mentioned targets are matched. Following Gertler and Karadi (2011), we initiate a financial crisis through a shock to the quality of capital ξ_t^k of 5%, with autocorrelation coefficient ρ_{ξ^k} set to 0.66.

TABLE 1 Model parameters

| Parameter | Value | Definition |
|----------------------------------|--------|---|
| <i>Households</i> | | |
| β | 0.99 | Subjective discount factor |
| σ | 1 | Risk aversion |
| h | 0.815 | Habit persistence parameter |
| χ | 3.6407 | Relative utility weight of labor |
| φ | 0.276 | Inverse Frisch elasticity |
| <i>Banking sector</i> | | |
| λ_k | 0.3863 | Fraction of divertable assets |
| χ_F | 0.0021 | Transfer to entering bankers |
| ϑ | 0.972 | Survival rate of bankers |
| <i>Non-financial firms</i> | | |
| α | 0.33 | Capital share in output |
| γ | 1.728 | Investment adjustment cost parameter |
| δ | 0.025 | Depreciation rate |
| <i>Autoregressive components</i> | | |
| ρ_A | 0.95 | Autoregressive component of productivity |
| ρ_{ξ^k} | 0.66 | Autoregressive component of capital quality |
| <i>Shocks</i> | | |
| σ_A | 0.01 | Standard deviation of productivity |
| σ_{ξ^k} | 0.05 | Standard deviation of capital quality |

IV. Results

In this section we present the results from our simulations. We start by providing a baseline scenario in which we investigate the response of our model economy to a negative capital quality shock as in Gertler and Karadi (2011), and compare the results from this simulation with several bail-in policies, which has become the main tool to deal with failing banks in the EU after the introduction of the BRRD in 2014.

A. An unanticipated bail-in after a financial crisis

Following Gertler and Karadi (2011), we initiate a financial crisis in our model economy with a negative capital quality shock $\varepsilon_{\xi^k,t}$ of 5%. In Figure 1 we compare the response of our model economy in the absence of any policy interventions (blue, solid) with an unanticipated bail-in that is implemented at the moment the financial crisis hits the economy (red, dashed), and consists of a partial write-off of gross interest payments (including the repayment of the principal). We set Ψ_t such that the total write-off $\Psi_t (1 + r_{t-1}^d) D_{t-1}$ amounts to 5% of annual steady state output.

Consider first the model response to a capital quality shock without any bail-ins (blue, solid line). The shock reduces the effective capital stock, lowering the ex-post return on banks' loans r_t^k , as can be seen from equation (3). Net worth N_t drops by approximately 50% of steady state net worth, which tightens the balance sheet constraint of financial intermediaries. The resulting increase in the credit spread causes demand for loans (and hence for physical capital) from final goods producers to fall, which leads to a drop in the price of capital Q_t^k . Such a price drop further reduces the ex-post return on capital r_t^k , see equation (3), and leads to a further reduction of net worth, which amplifies the effects from the initial capital quality shock. Since final goods producers need funding from financial intermediaries to be able to purchase physical capital K_t , the lower demand for loans leads to lower investment I_t and a fall in the capital stock. In addition, the financial crisis reduces households' income, which leads to a drop in consumption. The subsequent drop in investment and consumption cause output Y_t to drop by approximately 4% with respect to the steady state.

All in all, a financial crisis caused by a quality of capital shock leads to a relatively severe recession: output falls by approximately 4% and investment by more than 10% with respect to the steady state.

Next we investigate whether an unanticipated bail-in, modeled as an immediate partial write-off of gross interest payments on deposits implemented at the moment the financial crisis hits, is capable of mitigating the adverse macroeconomic consequences of the banking crisis (red, dashed line in Figure 1). The bail-in clearly has positive effects on the economy: output still falls on impact, but the trough is not as low as in the no intervention case. Investment also falls by less and recovers more quickly. The reason is that the bail-in reduces gross interest payments to depositors, which leaves more net worth in the banking system. Higher net worth (relative to the no intervention case) relaxes intermediaries' balance sheet constraints, which allows them to expand lending to final goods producers. More lending allows final goods producers to increase investment, and a higher capital

stock raises the marginal product of labor which increases households' incomes (not shown). As a result, consumption increases relative to the no intervention case. Hence, an immediate bail-in is quite effective at alleviating the negative macroeconomic effects from a financial crisis, as investment and output fall by less.

Although our results show that an unanticipated bail-in is effective at ameliorating macroeconomic conditions during a financial crisis, investors and financial market participants usually learn about financial troubles (and the possibility of a bail-in) before regulators officially acknowledge banking sector troubles. And even if this were not the case, there can be a lag between the announcement of a bail-in and its execution due to legal and political constraints, which allows investors to withdraw their funds before implementation. Therefore, the assumption that the bail-in is unanticipated might not be entirely realistic.

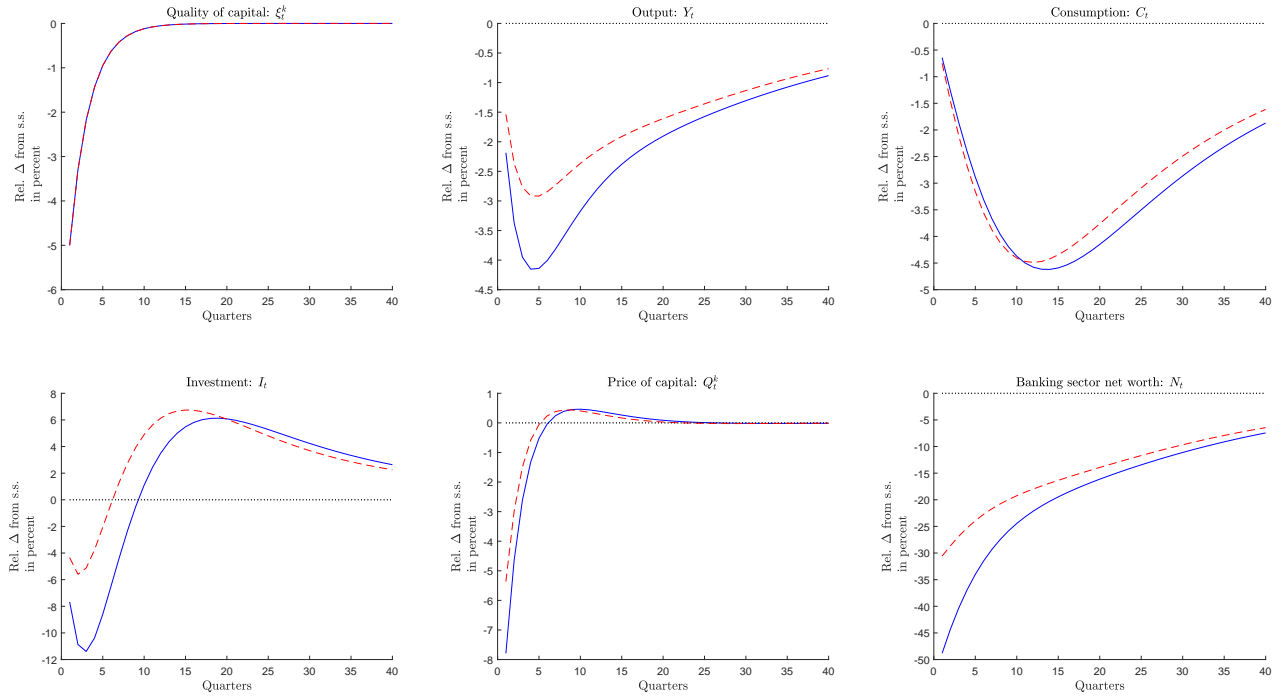
B. The macroeconomic implications of an anticipated bail-in

Although we showed that an unanticipated bail-in can improve macroeconomic conditions during a financial crisis, it is more likely that a bail-in will be anticipated by investors and financial market participants. Even in the case of Cyprus, which was the first time a bail-in was implemented in modern history, the possibility of a write-down of uncovered bank debt already surfaced in January of 2013 (Thomas (2013), Fidler et al. (2013)), two months before the bail-in was announced in March 2013.

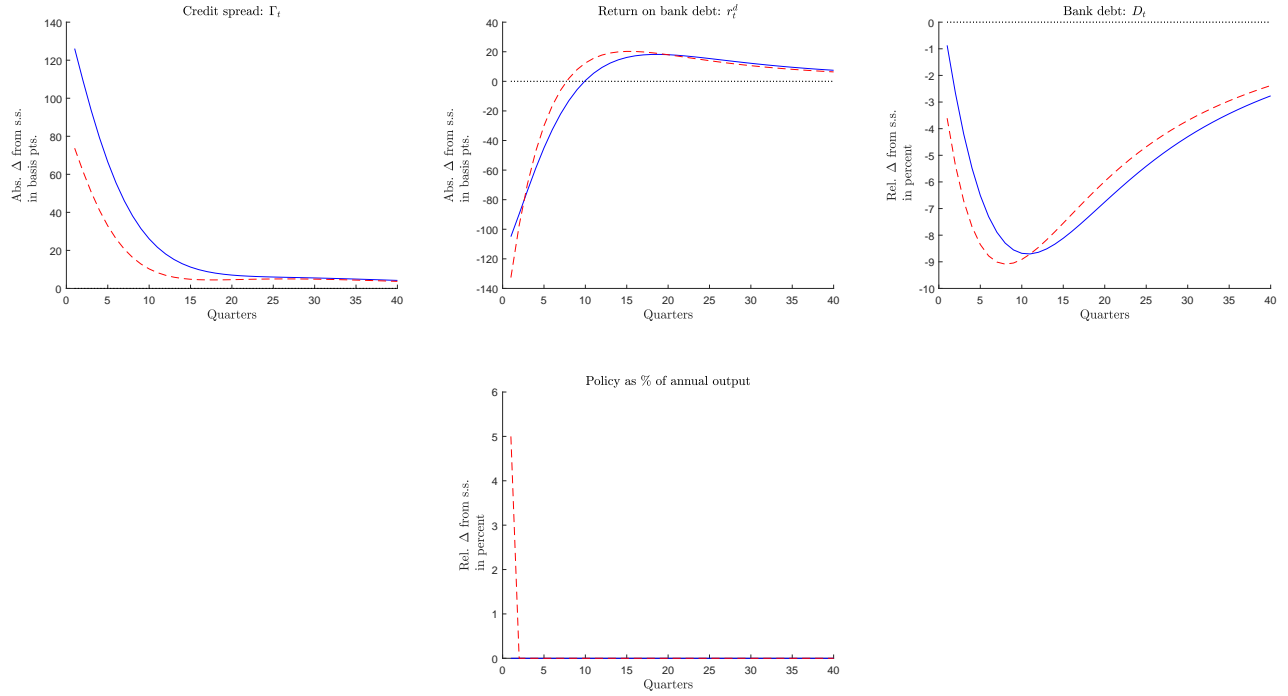
In line with these observations, we turn to a scenario where a bail-in is anticipated by creditors: at the moment the financial crisis hits, households (correctly) anticipate that a bail-in will be implemented one quarter later. The results of this simulation are presented in Figure (2), in which we compare the no policy case (blue, solid) with an anticipated bail-in (red, dashed). Again, a total amount $\Psi_t (1 + r_{t-1}^d) D_{t-1}$ equal to 5% of annual steady state output is written off.

The impulse response functions show that an anticipated bail-in has zero effect on the real economy. As the bail-in is anticipated, households start withdrawing their debt holdings in the period before they (correctly) expect the bail-in to be implemented. As there is perfect competition in the market for short-term debt, and with prices and interest rates perfectly flexible, banks are forced to raise interest rates to such an extent that the future gains in net worth from the partial write-off are transferred to households. In equilibrium, the deposit interest rate r_t^d increases by 300 basis points. As a result, the credit spread, which is the difference between the expected return on loans and the interest rate r_t^d on deposits, drops by 300 basis points in the first period. Because the banks' gains from the bail-in are exactly offset by higher interest payments, the net impact of an anticipated bail-in on net worth is zero, and hence there is no impact on the real economy.

With zero impact on the economy relative to the no policy intervention case, the question arises whether bail-ins in general, and the 2013 Cypriot bail-in in particular, are an effective policy to deal with a failing banking system from a macroeconomic perspective. However, in the case of Cyprus the bail-in was accompanied by the imposition of capital controls, which made it more difficult, or even impossible for creditors to withdraw their funds from the bank. Did these capital controls make



(A)



(B)

FIGURE 1. Impulse response functions for model without policy intervention (blue, solid) vs. model with immediate bail-in, where bank debt equal to 5% of annual steady state output is written down (red, dashed). The financial crisis is initiated through a capital quality shock of 5%.

the bail-in more effective? Can a tax on deposit outflows, which is the closed-economy equivalent of capital controls, improve the macroeconomic effectiveness of (anticipated) bail-ins? This is the question we turn to in the next section.

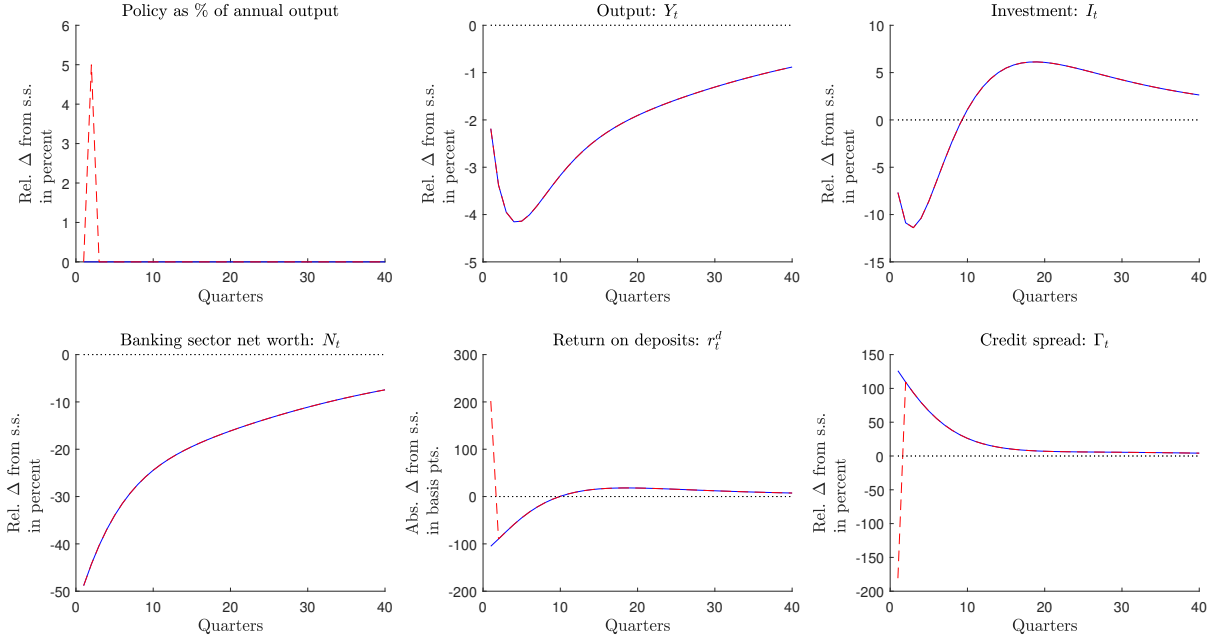


FIGURE 2. Impulse response functions for model without policy intervention (blue, solid) vs. model with anticipated bail-in that is executed one quarter after the shock arrives, where bank debt equal to 5% of annual steady state output is written down (red, dashed). The financial crisis is initiated through a capital quality shock of 5%.

C. Taxing deposit outflows

We showed in the previous section that anticipated bail-ins have zero impact on the macroeconomy compared with no policy intervention. In this section we investigate whether the imposition of an unexpected temporary tax on deposit outflows can make an anticipated bail-in more effective, see also Gertler et al. (2012), Jeanne and Korinek (2010a,b), and Korinek (2011).

We saw in the previous section that the effects of the anticipated bail-in manifest themselves in the form of a higher interest rate on deposits r_t^d in the period before the bail-in is imposed, as bank creditors (correctly) take into account that not all promised payments will be honored. The crucial mechanism through which this higher interest rate is established, is that depositors have the ability to withdraw their funds without any costs. We therefore investigate whether making it more difficult for creditors to withdraw their funds, by unexpectedly imposing a tax on deposit outflows in the period before creditors (correctly) anticipate a bail-in, can improve the macroeconomic effectiveness of the bail-in policy.

Just as in the previous section, we will investigate a bail-in which is (correctly) anticipated by bank creditors in the period in which the financial crisis hits the economy (period 1), but implemented one quarter later (period 2). In our simulations, we will implement an unexpected temporary tax on deposit outflows in period 1 ($\tau_1 > 0$), while setting the tax on deposit outflows

equal to zero in all subsequent periods $\tau_t = 0$ for all $t > 1$. But before going to the simulations, we will first show that a properly chosen sequence of tax-rates τ_t can completely offset the behavioral effects from the anticipated bail-in:

Proposition 1. *The behavioral effects of a (correctly) anticipated bail-in in period $t + 1$ can be completely offset by (unexpectedly) setting the tax rate τ_t on deposit outflows in period t equal to the fraction of gross interest payments Ψ_{t+1} that will be written off under the bail-in in period $t + 1$, while setting the tax rate equal to zero afterwards.*

Proof. Substitution of $\tau_t = \Psi_{t+1}$ and $\tau_{t+1} = 0$ into the household's Euler equation for bank debt 1 leads to the following first-order condition for bank debt holdings:

$$E_t \left[\beta \Lambda_{t,t+1} \left(1 + r_t^d \right) \right] = 1. \quad (15)$$

As Ψ_{t+1} no longer features in the household's Euler equation, there is no behavioral effect from the anticipated bail-in on household's savings decision. \square

The intuition behind this result is the following: the anticipation of a bail-in effectively reduces gross interest payments in period $t + 1$ (on funds D_t deposited in period t) by a fraction Ψ_{t+1} . However, reducing D_t by one euro through withdrawing requires paying a tax Ψ_{t+1} in period t . Households' deposit holdings are therefore effectively reduced by a fraction Ψ_{t+1} , irrespective whether they continue saving or withdraw deposits from the bank. Hence, the anticipated bail-in will no longer affect households' savings decisions.

We now turn to the simulations in Figure 3 where we compare the anticipated bail-in from the previous section (blue, solid) with the case where deposit outflows are taxed one period before the bail-in is implemented *in addition* to the anticipated bail-in from the previous section (red, dashed). We clearly see that such a tax restores the effectiveness of the bail-in policy, as net worth, investment and output increase with respect to the case where no such tax is implemented.

The economic intuition behind this result is relatively straightforward: the tax on deposit outflows removes the possibility for households to avoid the negative consequences of the anticipated bail-in by withdrawing their funds, as their current stock of deposit holdings will be reduced by a fraction Ψ_{t+1} irrespective of whether they withdraw or not. Unlike the previous section, the incentive to start withdrawing disappears. This removes the need for banks to raise interest rates that was previously necessary to induce households to keep their deposits in the bank. Hence the removal of the need to raise interest rates allows banks to keep the gains from the anticipated future bail-in.

We show in Figure 4 in the Appendix that the results from the unanticipated bail-in and an anticipated bail-in with an (unexpected) tax on deposit outflows shown in this section are equivalent. The reason is that in both cases the household's savings decisions are unaffected by the bail-in. Hence households will in both cases make the same savings decisions once the bail-in has been implemented, which allows the banking sector to obtain all the gains in net worth from the bail-in.

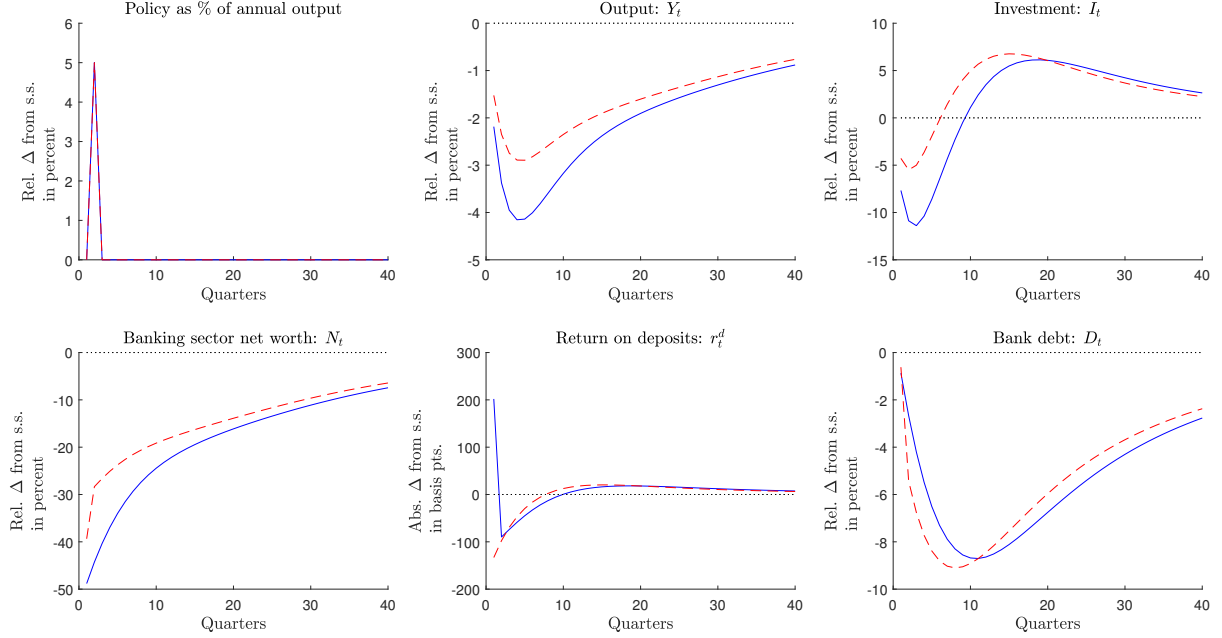


FIGURE 3. Impulse response functions for model with anticipated bail-in that is executed one quarter after the shock arrives without tax on deposit outflows (blue, solid) vs. model with anticipated bail-in that is executed one quarter after the shock arrives with (unanticipated) tax on deposit outflows in the period before the anticipated bail-in (red, dashed). Both interventions have bank debt write downs equal to 5% of annual steady state output. The financial crisis is initiated through a capital quality shock of 5%.

The results from this section show that the effectiveness of an anticipated bank bail-in can be restored by unexpectedly implementing a temporary tax on deposit outflows. This rationalizes the imposition of capital controls, which can be thought of as a tax on deposit outflows within our framework, by the Cypriot government once it was agreed that its banking system would be recapitalized through a bail-in of bank creditors. Clearly, in a European Union with free movement of capital, such a step came completely unexpected, which validates the assumption in our simulations regarding the expectations of such a tax on deposit outflows.

V. Discussion

In this section we discuss some of the (implicit) assumptions we have made, and how these affect our results.

First, one could argue that it is not clear whether a bank that is undercapitalized and perhaps insolvent has the capacity to pay a higher interest rate on its liabilities, which is the main mechanism through which the effectiveness of the bail-in is reduced in our paper. However, this does not necessarily invalidate our qualitative result regarding the macroeconomic effectiveness of anticipated bail-ins. When banks cannot pay higher interest rates, creditors will start withdrawing deposits compared with the no-intervention case. This forces the bank to shrink the balance sheet and negatively affects credit provision to the real economy. Similarly to our mechanism, this would reduce the effectiveness of the intervention.

This brings us to a second reservation, namely that the anticipation of a bail-in might induce a bank run, which is a feature we do not incorporate. In that case, a bail-in will not be effective, which is in line with the main result of our paper. It is an interesting avenue for future research to investigate the effectiveness of bank bail-ins when banks can be subject to bank runs. Implementing bank runs would require solving the model with global solution methods (Gertler and Kiyotaki (2015), Gertler et al. (2016), Gertler et al. (2017)), which we leave for future projects.

A third reservation is that a significant part of bank liabilities consists of long-term debt. When these claims do not have to be repaid before the bail-in is imposed, this would surely mitigate the stark results that we find in our current setup, as creditors cannot force the bank to raise interest rates on outstanding long-term liabilities (although the yield on such claims would surely increase if these claims are traded in financial markets). However, our results would qualitatively still go through, as a significant fraction of bank liabilities is short-term, while some of the longer-term liabilities might have to be rolled over in the period between when financial markets start to anticipate a bail-in and its actual implementation. At the time of such a roll-over, long-term creditors would either withdraw their funds or demand a higher interest rate to compensate for the future losses arising from the bail-in, which again would reduce the macroeconomic effectiveness of the bail-in.

A fourth reservation might be that banks in our setup do not go bankrupt in the absence of a bail-in, while one of the three conditions to be fulfilled before the bail-in tool can be employed is that a bank is failing or likely to fail (FLTF) (Hüser et al., 2017). The mechanism through which bail-ins become ineffective in our paper, however, is through higher interest payments that are promised *before* the banking system goes actually bankrupt. Whether or not the banking system would go bankrupt does not matter for our results, as long as the ex-post-bail-in return that investors expected is honored. That conclusion might change if the regulator implements a larger bail-in than expected by investors. In that case, investors have not priced in the bail-in correctly, in which case the bail-in becomes more effective as not all gains are transferred to bank creditors.

The message of our paper seems to be that bail-ins are not very effective as a macroeconomic policy tool. That, however, would be too quick of a conclusion, as our paper does not investigate long-run financial stability issues. From that angle, one could arrive at different conclusions, as our model abstracts from moral hazard issues: the knowledge that shareholders and bank creditors might be bailed in, could induce banks to take less risk, and thereby reduce the probability of future financial crises (ECB, 2016). This beneficial effect of bail-ins is absent in our model.

VI. Conclusion

Motivated by the Cypriot bail-in of 2013 and the adoption of the Bank Recovery and Resolution Directive (BRRD) in the EU in 2014, we investigate the macroeconomic effectiveness of bailing in bank creditors in response to a systemic financial crisis through its effect on the credit transmission channel. We construct a closed economy RBC model enriched with a balance-sheet-constrained banking sector à la Gertler and Karadi (2011) in which the size of the balance sheet is limited by

the amount of bank net worth. We model a bail-in as a partial write-off of both principal and promised interest payments on bank debt, which increases commercial banks' net worth relative to no intervention everything else equal.

Our simulations show that an immediate, unanticipated bail-in of depositors is effective at alleviating the negative effects of a financial crisis. The bail-in reduces the fall in net worth, which alleviates banks' balance sheet constraint. As banks' endogenous leverage constraints are relaxed, they expand credit provision to the real economy, which reduces the drop in investment and output relative to the no intervention case.

In reality, however, bail-ins seldom occur unexpectedly. Investors and financial market participants usually detect financial troubles in the banking system before regulators will officially acknowledge financial sector troubles and implement a bail-in of bank creditors. And even if they do, there is usually time between the announcement of the bail-in and its implementation due to legal and political constraints. Therefore, we investigate the more realistic case of an anticipated bail-in, in which bank creditors start to (correctly) expect a partial write-off of both principal and interest payments as a financial crisis hits, which is implemented one quarter later. We find that a bail-in in such a scenario has zero impact on the real economy compared with no policy intervention: as depositors know that their promised gross interest payments (including principal) will not be fully honored, they start withdrawing their funds in the period before they anticipate the bail-in to be implemented. With a perfectly competitive deposit market, and perfectly flexible prices and interest rates, banks have to raise interest rates to such an extent that the future gains from the bail-in are transferred back to depositors. As a result, the change in net worth compared to the no intervention case is zero, which leaves the real economy unaffected as the lending expansion observed under an unanticipated bail-in does not materialize.

Our results imply that in a world of perfect capital mobility, a correctly anticipated bail-in is ineffective as a macroeconomic policy tool in dealing with a financial crisis. We show, however, that the bail-in policy regains its effectiveness when an unanticipated temporary tax is levied on deposit outflows in addition to the bail-in. As the costs of withdrawing bank debt increases, banks do not need to raise interest rates to keep deposits in the bank, which allows them to keep the bail-in gains. This result rationalizes why the Cypriot government not only imposed a bail-in on bank creditors in March 2013, but in addition imposed capital controls to prevent bank creditors from withdrawing their funds.

Our paper seems to raise doubts whether bail-ins are the preferred policy to deal with failing banks, as foreseen by the BRRD. However, we do not investigate long-run financial stability issues: for example banks might take less risk if they know that shareholders and bank creditors might be bailed in, which reduces the probability of future financial crises (ECB, 2016). Hence from a financial stability perspective, bail-ins might still be a good idea.

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A. Mathematical appendix

A. Household

The household's optimization problem is to maximize expected, discounted lifetime utility:

$$\max_{\{C_{t+s}, L_{t+s}, D_{t+s}\}_{s=0}^{\infty}} E_t \left\{ \sum_{s=0}^{\infty} \beta^s \left[\frac{1}{1-\sigma} (C_{t+s} - hC_{t+s-1})^{1-\sigma} - \frac{\chi}{1+\varphi} L_{t+s}^{1+\varphi} \right] \right\}, \quad (16)$$

$$\beta \in (0, 1), h \in [0, 1), \varphi \geq 0,$$

The next step in finding a solution to the household's optimization problem is to maximize the household's lifetime utility function (16) subject to the following budget constraint:

$$C_t + D_t + T_t + \tau_t (D_{t-1} - D_t) = W_t L_t + \left(1 + r_{t-1}^d\right) (1 - \Psi_t) D_{t-1} + \Pi_t, \quad (17)$$

Using the utility function and the household budget constraint, we set up the following Lagrangian:

$$\begin{aligned} \mathcal{L} = & E_t \left\{ \sum_{s=0}^{\infty} \beta^s \left[\frac{1}{1-\sigma} (C_{t+s} - hC_{t+s-1})^{1-\sigma} - \frac{\chi}{1+\varphi} L_{t+s}^{1+\varphi} \right] \right\} \\ & + E_t \left\{ \sum_{s=0}^{\infty} \beta^s \lambda_{t+s} \left[W_{t+s} L_{t+s} + \left(1 + r_{t+s-1}^d\right) (1 - \Psi_{t+s}) D_{t+s-1} + \Pi_{t+s} \right. \right. \\ & \left. \left. - C_{t+s} - D_{t+s} - T_{t+s} - \tau_{t+s} (D_{t+s-1} - D_{t+s}) \right] \right\}. \end{aligned} \quad (18)$$

Solving the household's optimization problem yields the following first order conditions:

$$C_t : \lambda_t = (C_t - hC_{t-1})^{-\sigma} - \beta h E_t (C_{t+1} - hC_t)^{-\sigma}, \quad (19)$$

$$L_t : \lambda_t W_t = \chi L_t^{\varphi}, \quad (20)$$

$$D_t : E_t \left\{ \beta \lambda_{t,t+1} \left(\frac{\left(1 + r_t^d\right) (1 - \Psi_{t+1}) - \tau_{t+1}}{1 - \tau_t} \right) \right\} = 1. \quad (21)$$

B. Non-financial firms

B.1. Final goods producers

The constant returns to scale production technology available to final goods firms is:

$$Y_{i,t} = A_t \left(\xi_t^k K_{i,t-1} \right)^\alpha L_{i,t}^{1-\alpha}. \quad (22)$$

Taking the first order condition with respect to labor, we get that the wage rate equals:

$$W_t = (1 - \alpha) \frac{Y_{i,t}}{L_{i,t}}. \quad (23)$$

The representative final goods firm's profits are equal to:

$$\Pi_{i,t}^f = Y_{i,t} + Q_t^k (1 - \delta) \xi_t^k K_{i,t-1} - (1 + r_t^k) Q_{t-1}^k K_{i,t-1} - W_t L_{i,t}, \quad (24)$$

which states that profits are equal to production plus the income gained after selling previous period's capital stock net of depreciation times the price of capital, minus the cost of capital and the wage bill. Since firms operate in a perfectly competitive environment, profits are zero. We plug the expression for the wage rate into the final goods firm's profit function, set the profit function to zero, and solve for the return on capital. This equals:

$$1 + r_t^k = \frac{\alpha \frac{Y_{i,t}}{K_{i,t-1}} + Q_t^k (1 - \delta) \xi_t^k}{Q_{t-1}^k}. \quad (25)$$

B.2. Capital goods producers

Final goods producers sell their used capital stock to capital producers. They sell the capital stock net of depreciation, i.e. $(1 - \delta)K_{t-1}$ for a price Q_t^k . Capital producers use the final good I_t to refurbish the depreciated capital stock. They face convex adjustment costs, which depend on the change in investment I_t relative to the previous period. The law of motion for capital is then:

$$K_t = (1 - \delta) \xi_t^k K_{t-1} + \left[1 - \frac{\gamma}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t. \quad (26)$$

Profits for capital goods producers are then the revenue they make from selling refurbished capital, minus the costs they incur when purchasing used capital and final goods used in the refurbishing process:

$$\Pi_t^k = Q_t^k K_t - Q_t^k (1 - \delta) \xi_t^k K_{t-1} - I_t. \quad (27)$$

The capital producers' maximization problem is then to maximize the sum of current and expected discounted future profits by finding the optimal path for investment I_t :

$$\max_{\{I_{t+s}\}_{s=0}^{\infty}} E_t \left\{ \sum_{s=0}^{\infty} \beta^s \Lambda_{t+s,t+1+s} \left[\left(1 - \frac{\gamma}{2} \left(\frac{I_{t+s}}{I_{t-1+s}} - 1 \right)^2 \right) Q_{t+s}^k I_{t+s} - I_{t+s} \right] \right\}, \quad (28)$$

where the household's stochastic discount factor is used to discount future profits, since the household owns the capital goods producing firms. Maximizing the objective function by differentiating with respect to I_t and rewriting yields an expression for the price of capital Q_t^k :

$$\frac{1}{Q_t^k} = 1 - \frac{\gamma}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \gamma \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} + E_t \left[\beta \Lambda_{t,t+1} \frac{Q_{t+1}^k}{Q_t^k} \gamma \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right] \quad (29)$$

B.3. Aggregation of non-financial firms

To find expressions for aggregate supply, we aggregate (22) for all firms i . Aggregation over the left hand yields:

$$\int_0^1 Y_{i,t} di = Y_t. \quad (30)$$

We can calculate the right hand side by integrating (22) over di :

$$\int_0^1 A_t \left(\xi_t^k K_{t-1} \right)^\alpha L_t^{1-\alpha} di = \int_0^1 A_t \left(\frac{\xi_t^k K_{i,t-1}}{L_{i,t}} \right)^\alpha L_{i,t} di. \quad (31)$$

We can find the capital-labor ratio by inspecting the factor prices. Rewriting these gives us that:

$$L_{i,t} = (1 - \alpha) \frac{Y_{i,t}}{W_t}, \quad (32)$$

$$K_{i,t-1} = \frac{\alpha Y_{i,t}}{(1 + r_t^k) Q_{t-1}^k - Q_t^k (1 - \delta) \xi_t^k}. \quad (33)$$

The ratio of these two is then equal to:

$$\frac{K_{i,t-1}}{L_{i,t}} = \frac{\alpha}{1 - \alpha} \left[\frac{W_t}{(1 + r_t^k) Q_{t-1}^k - Q_t^k (1 - \delta) \xi_t^k} \right], \quad (34)$$

where we can clearly see that the individual capital-labor ratio does not depend on any individual firm characteristics. Hence, all firms choose the same capital-labor ratio, since $\frac{K_{i,t-1}}{L_{i,t}} = \frac{K_{t-1}}{L_t}$. As such, we can aggregate the aggregate supply function in the following way:

$$\int_0^1 A_t \left(\frac{\xi_t^k K_{i,t-1}}{L_{i,t}} \right)^\alpha L_{i,t} di = A_t \left(\frac{\xi_t^k K_{t-1}}{L_t} \right)^\alpha \int_0^1 L_{i,t} di = A_t \left(\xi_t^k K_{t-1} \right)^\alpha L_t^{1-\alpha}. \quad (35)$$

Hence, aggregate output is equal to:

$$Y_t = A_t \left(\xi_t^k K_{t-1} \right)^\alpha L_t^{1-\alpha}. \quad (36)$$

C. Banking sector

C.1. Optimization problem

Banks can invest in loans to intermediate goods firms $S_{j,t}^k$ for a price Q_t^k . Banks fund themselves through net worth $N_{j,t}$ and deposits $D_{j,t}$. The balance sheet of a bank j is therefore given by:

$$Q_t^k S_{j,t}^k = N_{j,t} + D_{j,t}. \quad (37)$$

The law of motion for net worth is:

$$N_{j,t+1} = \left(1 + r_{t+1}^k \right) Q_t^k S_{j,t}^k - \left(1 + r_t^d \right) (1 - \Psi_{t+1}) D_{j,t} \quad (38)$$

The bank maximizes expected discounted future profits:

$$V_{j,t} = \max_{\{S_{j,t}^k, D_{j,t}\}} E_t \{ \beta \Lambda_{t,t+1} [(1 - \vartheta) N_{j,t+1} + \vartheta V_{j,t+1}] \} \quad (39)$$

As in Gertler and Karadi (2011), there is a principal-agent problem between banks and depositors. This is characterized by the following incentive compatibility constraint:

$$V_{j,t} \geq \lambda_k Q_t^k S_{j,t}^k \quad (40)$$

A typical bank's optimization problem is therefore given by:

$$\begin{aligned} V_{j,t} &= \max_{\{S_{j,t}^k, D_{j,t}\}} E_t \{ \beta \Lambda_{t,t+1} [(1 - \vartheta) N_{j,t+1} + \vartheta V_{j,t+1}] \}, \\ &\text{s.t.} \\ V_{j,t} &\geq \lambda_k Q_t^k S_{j,t}^k, \\ Q_t^k S_{j,t}^k &= N_{j,t} + D_{j,t}, \\ N_{j,t} &= \left(1 + r_t^k \right) Q_{t-1}^k S_{j,t-1}^k - \left(1 + r_{t-1}^d \right) (1 - \Psi_t) D_{j,t-1}. \end{aligned}$$

where $V_{j,t} \equiv V(S_{j,t-1}^k, D_{j,t-1})$. We set up the following Lagrangian:

$$\begin{aligned} \mathcal{L} &= (1 + \mu_t) E_t \left\{ \beta \Lambda_{t,t+1} \left[(1 - \vartheta) \left(\left(1 + r_{t+1}^k \right) Q_t^k S_{j,t}^k - \left(1 + r_t^d \right) (1 - \Psi_{t+1}) D_{j,t} \right) + \vartheta V_{j,t+1} \right] \right\} \\ &\quad - \mu_t \lambda_k Q_t^k S_{j,t}^k + \chi_t \left\{ \left(1 + r_t^k \right) Q_{t-1}^k S_{j,t-1}^k - \left(1 + r_{t-1}^d \right) (1 - \Psi_t) D_{j,t-1} + D_{j,t} - Q_t^k S_{j,t}^k \right\} \end{aligned} \quad (41)$$

This yields the following first order conditions:

$$S_{j,t}^k : (1 + \mu_t) E_t \left\{ \beta \Lambda_{t,t+1} \left[(1 - \vartheta) \left[(1 + r_{t+1}^k) Q_t^k \right] + \vartheta \frac{\partial V_{j,t+1}}{\partial S_{j,t}^k} \right] \right\} - \mu_t \lambda_k Q_t^k - \chi_t Q_t^k = 0 \quad (42)$$

$$D_{j,t} : (1 + \mu_t) E_t \left\{ \beta \Lambda_{t,t+1} \left[- (1 - \vartheta) (1 + r_t^d) (1 - \Psi_{t+1}) \right] + \vartheta \frac{\partial V_{j,t+1}}{\partial D_{j,t}} \right\} + \chi_t = 0. \quad (43)$$

Note that we do not yet have an expression for the partial derivatives of the next period's value function in the first order condition. By applying the envelope theorem we can get expressions for these partial derivatives:

$$\frac{\partial V_{j,t}}{\partial S_{j,t-1}^k} = \chi_t (1 + r_t^k) Q_{t-1}^k, \quad (44)$$

$$\frac{\partial V_{j,t}}{\partial D_{j,t-1}} = -\chi_t (1 + r_{t-1}^d) (1 - \Psi_t). \quad (45)$$

Iterating these forward and plugging them into the first order conditions, we get that:

$$S_{j,t}^k : E_t \left\{ \beta \Lambda_{t,t+1} [(1 - \vartheta) + \vartheta \chi_{t+1}] (1 + r_{t+1}^k) \right\} = \lambda_k \left(\frac{\mu_t}{1 + \mu_t} \right) + \frac{\chi_t}{1 + \mu_t} \quad (46)$$

$$D_{j,t} : E_t \left\{ \beta \Lambda_{t,t+1} [(1 - \vartheta) + \vartheta \chi_{t+1}] (1 + r_t^d) (1 - \Psi_{t+1}) \right\} = \frac{\chi_t}{1 + \mu_t}. \quad (47)$$

Next, we define the following variables:

$$\eta_t = \frac{\chi_t}{1 + \mu_t}, \quad (48)$$

$$\nu_t^k = \lambda_k \left(\frac{\mu_t}{1 + \mu_t} \right). \quad (49)$$

If we then subtract the FOC for deposits from the FOC for loans, our first order conditions become:

$$\begin{aligned} \nu_t^k &= \lambda_k \left(\frac{\mu_t}{1 + \mu_t} \right) = E_t \left\{ \beta \Lambda_{t,t+1} [(1 - \vartheta) + \vartheta \chi_{t+1}] (1 + r_{t+1}^k) \right\} - \eta_t \\ &= E_t \left\{ \beta \Lambda_{t,t+1} [(1 - \vartheta) + \vartheta (1 + \mu_{t+1}) \eta_{t+1}] (1 + r_{t+1}^k - (1 + r_t^d) (1 - \Psi_{t+1})) \right\} \end{aligned} \quad (50)$$

$$\eta_t = E_t \left\{ \beta \Lambda_{t,t+1} [(1 - \vartheta) + \vartheta (1 + \mu_{t+1}) \eta_{t+1}] (1 + r_t^d) (1 - \Psi_{t+1}) \right\}. \quad (51)$$

Next, we assume that a typical bank's value is linear in loans and deposits:

$$V_{j,t} = \nu_t^k Q_t^k S_{j,t}^k + \eta_t N_{j,t}. \quad (52)$$

Iterating forward and plugging this into the Bellman equation, we get that:

$$V_{j,t} = E_t \left\{ \beta \Lambda_{t,t+1} \left[(1 - \vartheta) N_{j,t+1} + \vartheta \left(\nu_{t+1}^k Q_{t+1}^k S_{j,t+1}^k + \eta_{t+1} N_{j,t+1} \right) \right] \right\}. \quad (53)$$

Assuming that the incentive compatibility constraint is binding at all times, we substitute that into the previous equation, slightly rewrite it and plug in the law of motion for net worth to get that:

$$\begin{aligned} V_{j,t} &= E_t \left\{ \beta \Lambda_{t,t+1} \left[(1 - \vartheta) + \vartheta \left(\nu_{t+1}^k \phi_{t+1} + \eta_{t+1} \right) \right] N_{j,t+1} \right\}, \\ &= E_t \left\{ \Omega_{t,t+1} \left[\left(1 + r_{t+1}^k - \left(1 + r_t^d \right) (1 - \Psi_{t+1}) \right) Q_t^k S_{j,t}^k + \left(1 + r_t^d \right) (1 - \Psi_{t+1}) N_{j,t} \right] \right\}, \end{aligned} \quad (54)$$

where $\Omega_{t,t+1} \equiv \beta \Lambda_{t,t+1} \left[(1 - \vartheta) + \vartheta \left(\nu_{t+1}^k \phi_{t+1} + \eta_{t+1} \right) \right]$. Comparing this result to our conjectured solution, we find the following first order conditions:

$$\nu_t^k = E_t \left\{ \Omega_{t,t+1} \left(1 + r_{t+1}^k - \left(1 + r_t^d \right) (1 - \Psi_{t+1}) \right) \right\}, \quad (55)$$

$$\eta_t = E_t \left\{ \Omega_{t,t+1} \left(1 + r_t^d \right) (1 - \Psi_{t+1}) \right\}, \quad (56)$$

where we can clearly see that our conditions coincide with those we found using the Lagrangian method. To derive the leverage ratio, we substitute the conjectured solution into the incentive compatibility constraint. This gives us that:

$$Q_t^k S_{j,t}^k \leq \phi_t N_{j,t}, \quad \phi_t = \frac{\eta_t}{\lambda_k - \nu_t^k}, \quad (57)$$

Finally, note that the stochastic discount factor of intermediaries is given by

$\Omega_{t,t+1} \equiv \beta \Lambda_{t,t+1} \left[(1 - \vartheta) + \vartheta \left(\nu_{t+1}^k \phi_{t+1} + \eta_{t+1} \right) \right]$ as well as by $\Omega_{t,t+1} \equiv \beta \Lambda_{t,t+1} \left[(1 - \vartheta) + \vartheta (1 + \mu_{t+1}) \eta_{t+1} \right]$. Hence we need to prove that for a binding incentive compatibility constraint $\nu_t^k \phi_t + \eta_t = (1 + \mu_t) \eta_t$. To do so we will employ that $\phi_t = \frac{\eta_t}{\lambda_k - \nu_t^k}$ and $\nu_t^k = \lambda_k \left(\frac{\mu_t}{1 + \mu_t} \right)$. Hence we can write:

$$\nu_t^k \phi_t + \eta_t = \nu_t^k \left(\frac{\eta_t}{\lambda_k - \nu_t^k} \right) + \eta_t = \left(\frac{\nu_t^k}{\lambda_k - \nu_t^k} + 1 \right) \eta_t = (1 + \mu_t) \eta_t,$$

where we have used

$$\nu_t^k = \lambda_k \left(\frac{\mu_t}{1 + \mu_t} \right) \Rightarrow \mu_t = \frac{\nu_t^k}{\lambda_k - \nu_t^k}.$$

C.2. Aggregation of financial variables

Aggregating over the balance sheet identity of all banks yields:

$$Q_t^k S_t^k = D_t + N_t. \quad (58)$$

We can also aggregate over banks the find the following macroeconomic leverage constraint:

$$\phi_t N_t = Q_t^k S_t^k. \quad (59)$$

Finally, the aggregate law of motion is given by the sum of net worth of existing banks and new banks:

$$N_t = \vartheta \left[\left(1 + r_t^k - \left(1 + r_{t-1}^d \right) (1 - \Psi_t) \right) Q_{t-1}^k S_{t-1}^k + \left(1 + r_{t-1}^d \right) (1 - \Psi_t) N_{t-1} \right] + \chi_F Q_{t-1}^k S_{t-1}^k. \quad (60)$$

D. Fiscal authority

The fiscal authority raises revenue by levying lump sum taxes T_t and a deposit tax τ_t on households. Note that lump sum taxes can also be negative. Hence, if the deposit tax increases, the proceeds are redistributed in a lump sum manner to households. The government budget constraint is therefore given by:

$$T_t + \tau_t (D_{t-1} - D_t) = 0. \quad (61)$$

The deposit tax takes the take the following functional form:

$$\tau_t = \zeta \varepsilon_{\xi^k, t-z}. \quad (62)$$

Hence the government imposes a tax on deposits τ_t in case a shock to the quality of capital hits the economy, i.e. if $\zeta < 0$. The tax on deposits can be carried out on impact ($z = 0$) or with a lag of one or more periods ($z > 0$).

Banks can also receive an injection of new net worth through a bail-in that converts a fraction Ψ_t of deposits into net worth after/during a credit crisis. This can be seen as a policy measure that is imposed by some sort of regulator, e.g. the Single Resolution Board (SRB) that oversees the resolution of banks in EU Member States. The bail-in variable is parametrized as follows:

$$\Psi_t = \varrho \varepsilon_{\xi^k, t-l}. \quad (63)$$

Deposits are written down if a shock to the quality of capital arrives, i.e. $\varrho < 0$. Like the recapitalization, the bail-in can be implemented on impact ($l = 0$) or with a lag ($l > 0$).

E. Market clearing

For the goods market to clear, output must equal the sum of consumption and investment:

$$Y_t = C_t + I_t. \quad (64)$$

The total amount of corporate loans must equal the total capital stock:

$$S_t^k = K_t. \quad (65)$$

B. Equilibrium conditions

The first order conditions for the household are:

$$\lambda_t = (C_t - hC_{t-1})^{-\sigma} - \beta h E_t(C_{t+1} - hC_t)^{-\sigma}, \quad (66)$$

$$\lambda_t W_t = \chi L_t^\varphi, \quad (67)$$

$$1 = E_t \left\{ \beta \Lambda_{t,t+1} \left(\frac{(1 + r_t^d)(1 - \Psi_{t+1}) - \tau_{t+1}}{1 - \tau_t} \right) \right\}. \quad (68)$$

The first order conditions for non-financial firms are:

$$Y_t = A_t (\xi_t^k K_{t-1})^\alpha L_t^{1-\alpha}, \quad (69)$$

$$K_t = (1 - \delta) \xi_t^k K_{t-1} + \left[1 - \frac{\gamma}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t, \quad (70)$$

$$\begin{aligned} \frac{1}{Q_t^k} &= 1 - \frac{\gamma}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \gamma \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \\ &\quad + E_t \left[\beta \Lambda_{t,t+1} \frac{Q_{t+1}^k}{Q_t^k} \gamma \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right], \end{aligned} \quad (71)$$

$$1 + r_t^k = \frac{\alpha \frac{Y_t}{K_{t-1}} + Q_t^k (1 - \delta) \xi_t^k}{Q_{t-1}^k}, \quad (72)$$

$$W_t = (1 - \alpha) \frac{Y_t}{L_t}. \quad (73)$$

The first order conditions for the banking sector are:

$$Q_t^k S_t^k = N_t + D_t, \quad (74)$$

$$\nu_t^k = E_t \left\{ \Omega_{t,t+1} \left(1 + r_{t+1}^k - (1 + r_t^d)(1 - \Psi_{t+1}) \right) \right\}, \quad (75)$$

$$\eta_t = E_t \left\{ \Omega_{t,t+1} \left(1 + r_t^d \right) (1 - \Psi_{t+1}) \right\}, \quad (76)$$

$$\phi_t N_t = Q_t^k S_t^k, \quad (77)$$

$$\phi_t = \frac{\eta_t}{\lambda_k - \nu_t^k}, \quad (78)$$

$$N_t = \vartheta \left[\left(1 + r_t^k - (1 + r_{t-1}^d)(1 - \Psi_t) \right) Q_{t-1}^k S_{t-1}^k + \left(1 + r_{t-1}^d \right) (1 - \Psi_t) N_{t-1} \right] + \chi_F Q_{t-1}^k S_{t-1}^k, \quad (79)$$

where $\Omega_{t,t+1} \equiv \left[(1 - \vartheta) + \vartheta \left(\nu_{t+1}^k \phi_{t+1} + \eta_{t+1} \right) \right]$. The evolution of fiscal variables is given by:

$$0 = T_t + \tau_t (D_{t-1} - D_t), \quad (80)$$

$$\tau_t = \zeta \varepsilon_{\xi^k, t-n}, \quad (81)$$

$$\Psi_t = \varrho \varepsilon_{\xi^k, t-l}. \quad (82)$$

Markets clear:

$$Y_t = C_t + I_t, \quad (83)$$

$$K_t = S_t^k. \quad (84)$$

Stochastic processes evolve according to:

$$\log(A_t) = \rho_A \log(A_{t-1}) + \varepsilon_{A,t}, \quad (85)$$

$$\log(\xi_t^k) = \rho_{\xi^k} \log(\xi_{t-1}^k) + \varepsilon_{\xi^k,t}. \quad (86)$$

C. Recursive competitive equilibrium

Let $\mathbf{X}_t = [C_{t-1}, S_{t-1}^k, K_{t-1}, D_{t-1}, N_{t-1}, I_{t-1}, Y_{t-1}, r_{t-1}^d, A_t, \xi_t^k]$ be the state vector. A recursive competitive equilibrium is a sequence of quantities $\{C_{t+s}, L_{t+s}, D_{t+s}, K_{t+s}, I_{t+s}, Y_{t+s}, S_{t+s}^k, N_{t+s}, \phi_{t+s}, \Psi_{t+s}, T_{t+s}, \tau_{t+s}\}_{s=0}^\infty$, prices $\{\lambda_{t+s}, r_{t+s}^d, r_{t+s}^k, W_{t+s}, Q_{t+s}^k, \nu_{t+s}^k, \eta_{t+s}\}_{s=0}^\infty$, and stochastic processes $\{A_{t+s}, \xi_{t+s}^k\}_{s=0}^\infty$ that satisfy::

- The first order conditions for the household: (66) - (68).
- The first order conditions for non-financial firms: (69) - (73).
- The first order conditions for the banking sector: (74) - (79).
- The time path for fiscal variables: (80) - (82).
- The markets for goods and financial assets clear: (83) - (84).
- The stochastic processes for productivity and capital quality: (85) - (86).

D. Robustness and other figures

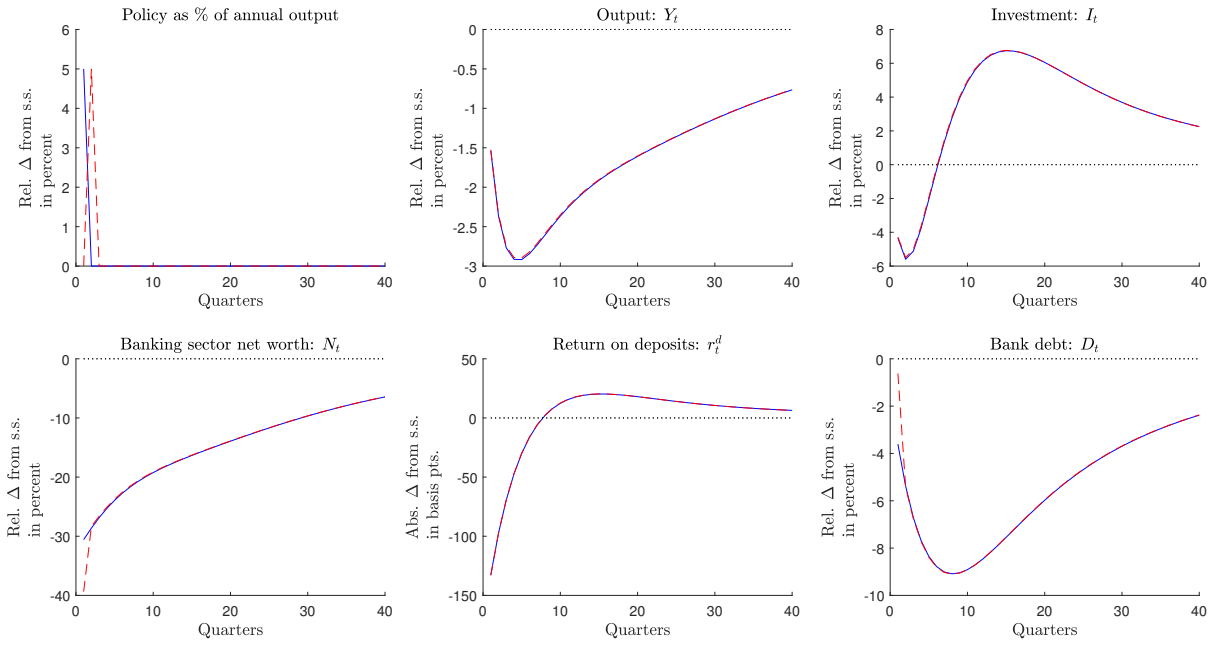


FIGURE 4. Impulse response functions for model with unanticipated bail-in (blue, solid) vs. model with anticipated bail-in that is executed one quarter after the shock arrives and unanticipated tax on short-term debt (red, dashed). Both interventions have bank debt write downs equal to 5% of annual steady state output. The financial crisis is initiated through a capital quality shock of 5%.

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